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(12) **United States Patent**  
**Schmidt et al.**(10) **Patent No.:** **US 9,257,607 B2**(45) **Date of Patent:** **Feb. 9, 2016**(54) **RED EMITTING LUMINESCENT MATERIALS**(75) Inventors: **Peter Josef Schmidt**, Aachen (DE);  
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U.S.C. 154(b) by 14 days.(21) Appl. No.: **13/988,852**(22) PCT Filed: **Nov. 28, 2011**(86) PCT No.: **PCT/IB2011/055329**

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(2013.01); **C09K 11/7734** (2013.01); **H01L**  
**33/502** (2013.01)(58) **Field of Classification Search**CPC ..... **H01L 33/502**; **H01L 33/50**; **H01L 33/26**;  
**C09K 11/0883**; **C09K 11/7734**

See application file for complete search history.

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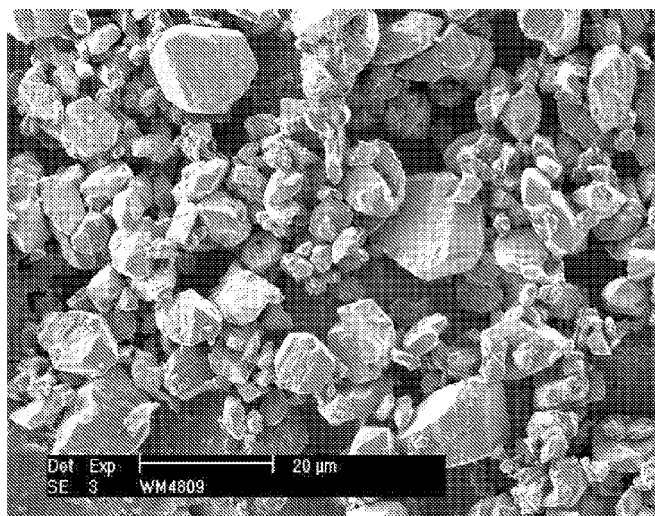
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*Primary Examiner* — Tucker J Wright(57) **ABSTRACT**The invention relates to a novel red emitting material of  
(Ba<sub>1-x-y-z</sub>Sr<sub>x</sub>Ca<sub>y</sub>Eu<sub>z</sub>)<sub>2</sub>Si<sub>5-a-b</sub>Al<sub>a</sub>N<sub>8-a-4b</sub>O<sub>a+4b</sub> having an  
average particle size distribution d<sub>50</sub> of >6 μm, with  
0.3≤x≤0.9, 0.01≤y≤0.1, 0.005≤z≤0.04, 0≤a≤0.2 and  
0≤b≤0.2.**4 Claims, 3 Drawing Sheets**

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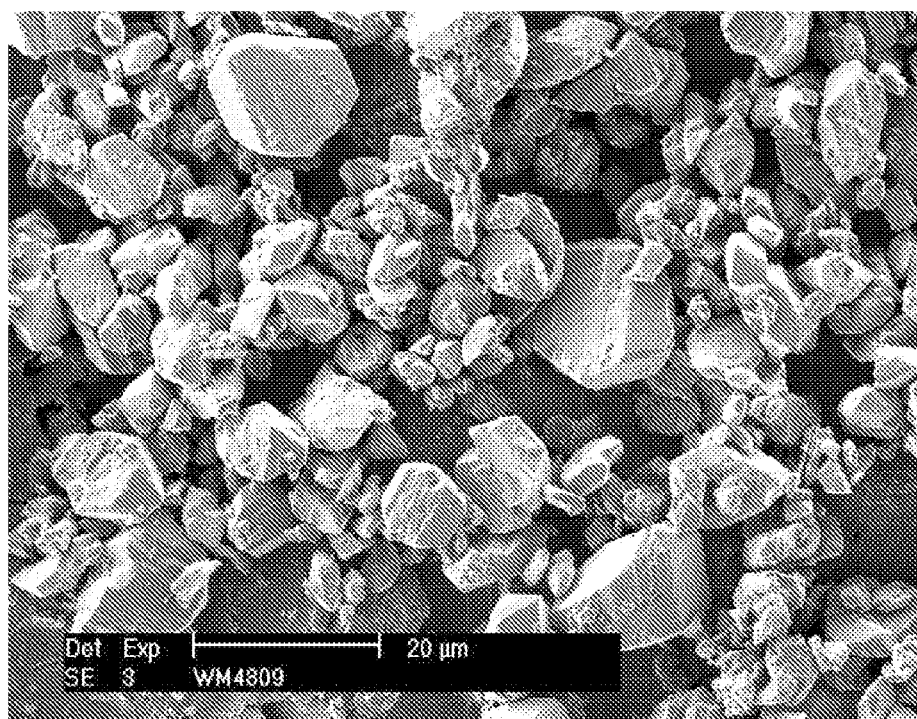


FIG. 1

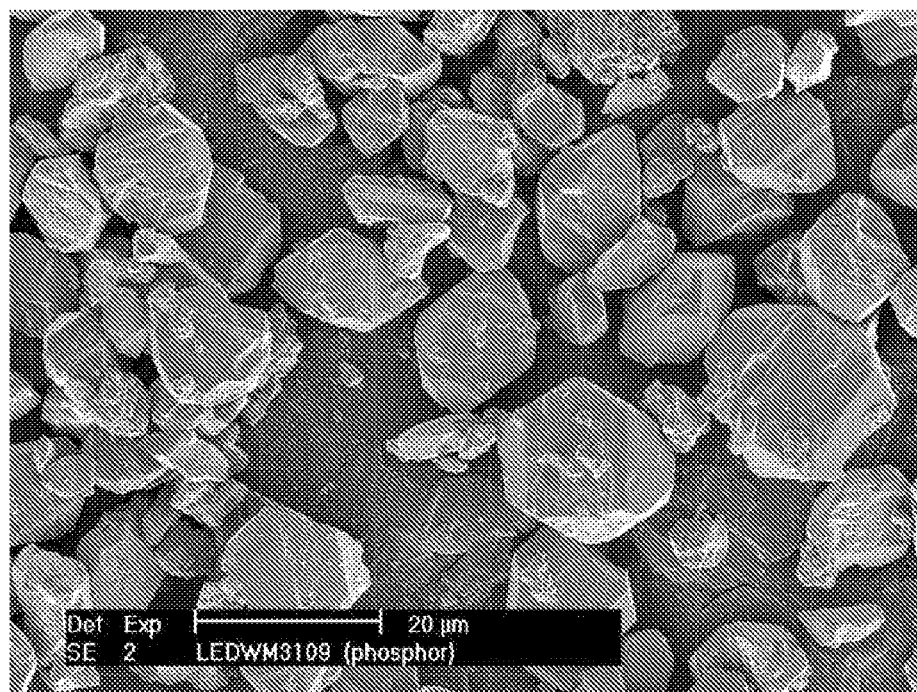


FIG. 2

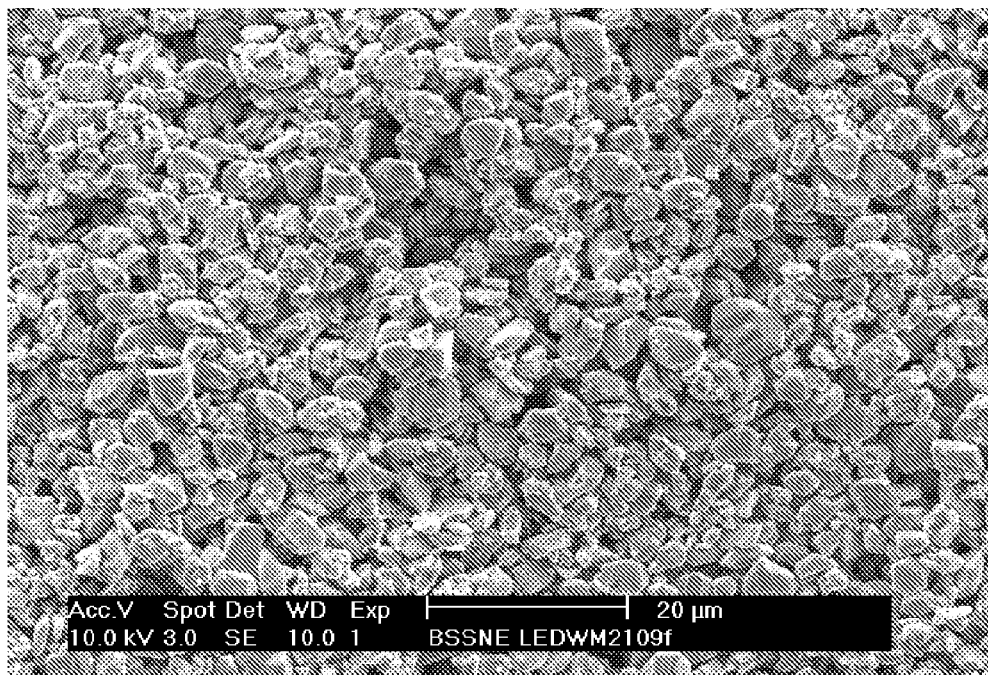


FIG. 3

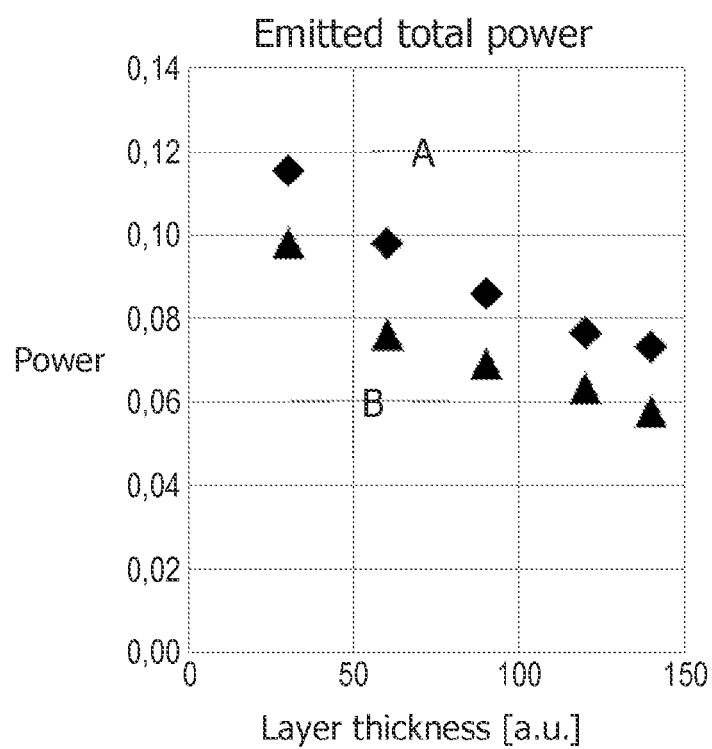


FIG. 4

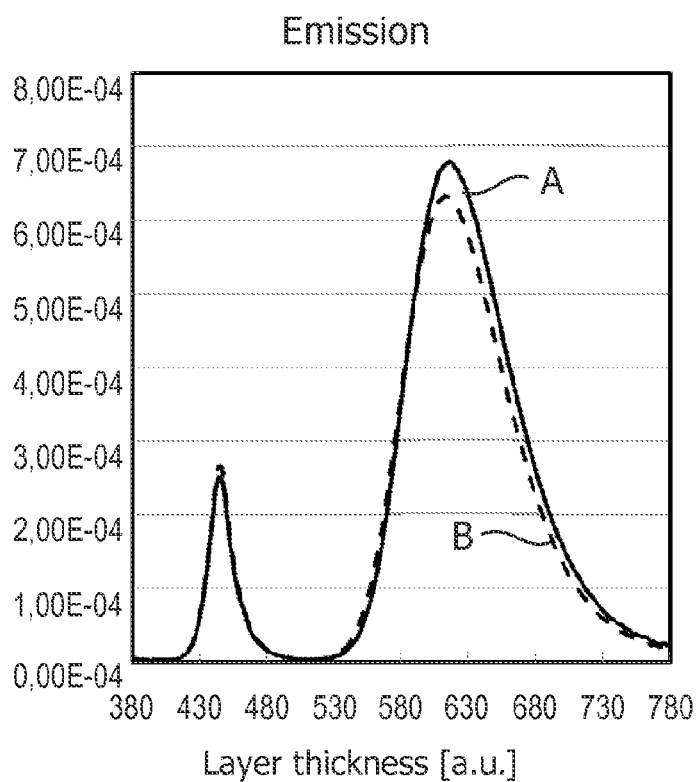


FIG. 5

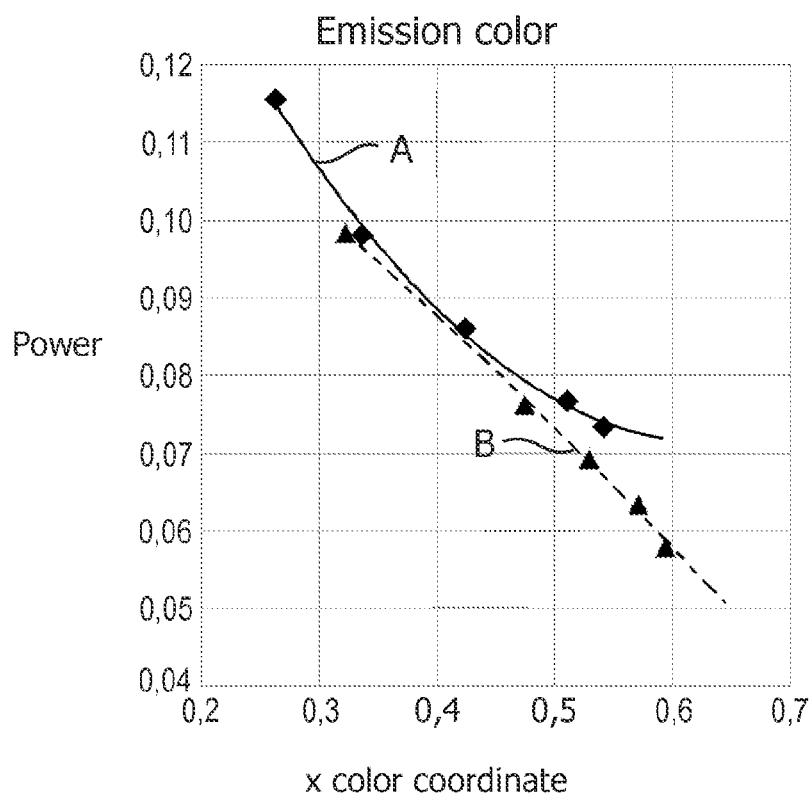


FIG. 6

# RED EMITTING LUMINESCENT MATERIALS

## FIELD OF THE INVENTION

The present invention is directed to novel luminescent materials for light emitting devices, especially to the field of novel luminescent materials for LEDs.

## BACKGROUND OF THE INVENTION

Phosphors comprising silicates, phosphates (for example, apatite) and aluminates as host materials, with transition metals or rare earth metals added as activating materials to the host materials, are widely known. As blue LEDs, in particular, have become practical in recent years, the development of white light sources utilizing such blue LEDs in combination with such phosphor materials is being energetically pursued.

Especially red emitting luminescent materials have been in the focus of interest and several materials have been proposed, e.g. U.S. Pat. No. 6,680,569(B2), "Red Deficiency Compensating Phosphor for a Light Emitting Device", or from WO patent application 2005/052087 A1.

However, there is still the continuing need for orange to red emitting luminescent materials which are usable within a wide range of applications and especially allow the fabrication of phosphor warm white pLEDs with optimized luminous efficiency and color rendering.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide a material which is usable within a wide range of applications and especially allows the fabrication of phosphor warm white pLEDs with optimized luminous efficiency and color rendering.

This object is solved by a material according to claim 1 of the present invention. Accordingly, a material  $(\text{Ba}_{1-x-y-z}\text{Sr}_x\text{Ca}_y\text{Eu}_z)_2\text{Si}_{5-a-b}\text{Al}_a\text{N}_{8-4b}\text{O}_{a+4b}$  having an average particle size distribution  $d_{50}$  of  $\geq 6 \mu\text{m}$  is provided, whereby

$$0.3 \leq x \leq 0.9, 0.01 \leq y \leq 0.1, 0.005 \leq z \leq 0.04, 0 \leq a \leq 0.2 \text{ and } 0 \leq b \leq 0.2.$$

It should be noted that by the term " $(\text{Ba}_{1-x-y-z}\text{Sr}_x\text{Ca}_y\text{Eu}_z)_2\text{Si}_{5-a-b}\text{Al}_a\text{N}_{8-4b}\text{O}_{a+4b}$ "—especially and/or additionally any material is meant and/or included, which has essentially this composition. This goes in analogy for all other materials mentioned in this invention.

The term "essentially" means especially that  $\geq 95\%$ , preferably  $\geq 97\%$  and most preferred  $\geq 99\%$  wt.%. However, in some applications, trace amounts of additives may also be present in the bulk compositions. These additives particularly include such species known to the art as fluxes. Suitable fluxes include alkaline earth—or alkaline—metal oxides, borates, phosphates and halides such as fluorides, ammonium chloride,  $\text{SiO}_2$  and the like and mixtures thereof.

Such a material has shown for a wide range of applications within the present invention to have at least one of the following advantages

Using the material as luminescent material, LEDs may be built which show improved lighting features, especially thermal stability.

The photostability of the material is greatly enhanced in contrast with materials having a smaller particle size

The material has a higher emission than comparable materials.

A similar material is known e.g. from the U.S. Pat. No. 7,671,529. However, surprisingly it has been found that by

using the material composition as described in this invention, a material with a larger average particle size and—depending on the actual application—furthermore advantageous material features can be achieved.

Without being bound to any theory the inventors believe that it is especially the content of calcium as described which leads to bigger particles (and which will be explained later on in greater detail).

Therefore this invention also relates to the use of calcium in siliconitridic materials for increasing the average particle size.

According to a preferred embodiment of the present invention,  $0.02 \leq y \leq 0.04$ . It has been shown that a calcium content in this amount is already sufficient to result in greater particle size, on the other hand larger amounts of Ca may possibly lead to unwanted broadening of the emission band and a thus lowered luminous efficiency of the phosphor material.

According to a preferred embodiment of the present invention,  $0.35 \leq x \leq 0.8$ , i.e. the Barium content is somewhat around 20% to 60% mol percent. This has been found to be advantageous for many applications due to the improved luminescence properties of the resulting material.

According to a preferred embodiment of the present invention,  $0 < b \leq 0.2$ , i.e. the material comprises oxygen. Surprisingly this has been found to greatly increase the photostability of the material for many applications within the present invention. Without being bound to any theory, it is believed that small amounts of  $\text{SiN}_4$  tetrahedra containing Si bridging N atoms are removed from the  $\text{M}_2\text{Si}_5\text{N}_8$  lattice and the resulting charge is compensated by terminal O atoms. However, in most applications it has been found that the oxygen content should not be too high, i.e. b should not exceed 0.2.

According to a preferred embodiment of the present invention, less than 10% of the phosphor particles show an average diameter  $\leq 2 \mu\text{m}$ . This has been found advantageous since by doing so for most applications the photostability may be enhanced.

According to a preferred embodiment of the present invention, for  $\geq 90\%$  of the phosphor particles the ratio of the longest and shortest particle edge length is  $\leq 5$ . This has been found advantageous since by doing so for most applications the industrial applicability can be eased.

As described above, the present invention relates to the use of calcium in siliconitridic materials for increasing the average particle size. This goes especially for materials of the type  $\text{M}_2\text{Si}_{5-a-b}\text{Al}_a\text{N}_{8-4b}\text{O}_{a+4b}$  (with  $0 \leq a \leq 2$  and  $0 < b \leq 2$ ), which are insofar preferred embodiments of the present invention.

It should be noted that the inventive use of calcium differs from the known use of flux materials, some of which are known to also enhance particle size. According to the invention, calcium is essentially evenly distributed in the powder whereas flux materials are usually not part of the luminescent material except for impurities.

According to a preferred embodiment of the present invention, the material has the structure  $\text{M}_2\text{Si}_{5-a-b}\text{Al}_a\text{N}_{8-4b}\text{O}_{a+4b}$ , with M being a divalent metal ion and with  $0 \leq a \leq 2$  and  $0 \leq b \leq 2$ .

According to a further preferred embodiment of the present invention, the material has the structure according to the present invention.

The present invention furthermore relates to a light emitting structure, especially a LED, comprising at least one material according to the present invention.

The present invention furthermore relates to a system comprising a material according to the present invention and/

or materials made according to the inventive methods shown above, being used in one or more of the following applications:

Office lighting systems  
household application systems  
shop lighting systems,  
home lighting systems,  
accent lighting systems,  
spot lighting systems,  
theater lighting systems,  
fiber-optics application systems,  
projection systems,  
self-lit display systems,  
pixelated display systems,  
segmented display systems,  
warning sign systems,  
medical lighting application systems,  
indicator sign systems, and  
decorative lighting systems  
portable systems  
automotive applications  
green house lighting systems

The aforementioned components, as well as the claimed components and the components to be used in accordance with the invention in the described embodiments, are not subject to any special exceptions with respect to their size, shape, material selection and technical concept such that the selection criteria known in the pertinent field can be applied without limitations.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Additional details, features, characteristics and advantages of the object of the invention are disclosed in the subclaims, the figures and the following description of the respective figures and examples, which—in an exemplary fashion—

FIG. 5 shows a diagram of emission vs. wavelength for two pcLEDs comprising the inventive and comparative material of FIG. 4, respectively; and

FIG. 6 shows a plot of the total emitted power as a function of the CIE x color coordinate for the two pcLEDs of FIG. 5

#### EXPERIMENTAL SECTION

The following invention will—together with the figures—furthermore be understood by the following examples which are merely for illustration purposes and which are non-binding.

#### General Preparation Method

All materials—whether inventive or comparative—were made according to the following prescription (and analogous deviations thereof):

Phosphors of compositions  $(\text{Ba}_{0.485-0.5x}\text{Sr}_{0.485-0.5x}\text{Ca}_x\text{Eu}_{0.03})_2\text{Si}_{4.99}\text{O}_{0.04}\text{N}_{7.96}$  with varying  $x=0, 0.01$  and  $0.02$  have been prepared by mixing of  $\text{BaH}_2$  (made by hydration of Ba rods, >99% purity),  $\text{SrH}_2$  (made by hydration of Sr granules, >99% purity),  $\text{CaH}_2$  (Aldrich),  $\text{Eu}_2\text{Si}_5\text{N}_8$  (made by reaction of  $\text{Eu}_2\text{O}_3$  with carbon and silicon nitride at  $1400^\circ\text{C}$ .),  $\text{Si}_3\text{N}_4$  (UBE SN E-10) with a molar ratio  $\text{Ba}+\text{Sr}+\text{Ca}+\text{Eu}/\text{Si}=0.417$  and firing twice with intermediate ball milling at  $1620^\circ\text{C}$ . in a molybdenum crucible under  $\text{H}_2/\text{N}_2$  atmosphere. After ball milling, screening and washing of the powders with 2N HCl, water and isopropanol and final drying, powder phosphors have been obtained.

A significant effect of Ca addition on grain growth can be observed by the change of particle size distribution (average particle diameter for a given volume fraction, measured by Laser scattering with a Beckman Coulter LS 200 series laser diffraction particle analyzer), as can be seen from Table I:

TABLE I

Sample composition	Inventive/Comparative	<10 vol %	<50 vol %	<90 vol %
$(\text{Ba}_{0.485}\text{Sr}_{0.485}\text{Eu}_{0.03})_2\text{Si}_{4.99}\text{O}_{0.04}\text{N}_{7.96}$	Comparative I	2.18 $\mu\text{m}$	4.03 $\mu\text{m}$	6.04 $\mu\text{m}$
$(\text{Ba}_{0.48}\text{Sr}_{0.48}\text{Ca}_{0.01}\text{Eu}_{0.03})_2\text{Si}_{4.99}\text{O}_{0.04}\text{N}_{7.96}$	Inventive Example I	2.64 $\mu\text{m}$	6.15 $\mu\text{m}$	13.37 $\mu\text{m}$
$(\text{Ba}_{0.475}\text{Sr}_{0.475}\text{Ca}_{0.02}\text{Eu}_{0.03})_2\text{Si}_{4.99}\text{O}_{0.04}\text{N}_{7.96}$	Inventive Example II	5.04 $\mu\text{m}$	10.27 $\mu\text{m}$	16.55 $\mu\text{m}$

show several embodiments and examples an inventive material according to the invention.

FIG. 1 shows a scanning electron image of a material according to Example I of the present invention

FIG. 2 shows a scanning electron image of a material according to Example II of the present invention

FIG. 3 shows a scanning electron image of a material according to a comparative Example

FIG. 4 shows a diagram of emission power vs. layer thickness for two pcLED comprising an inventive and a comparative material, respectively; and

FIGS. 1 to 3 show scanned electron images of the powders of Inventive Example I, inventive Example II and the comparative Example (no calcium), respectively.

To further illustrate the advantageous feature of the intensive material, the photostability of Inventive Example III (see below) and the Comparative example were investigated.

It was found that the emission intensity decrease after 1 h irradiation with 10 W/cm<sup>2</sup> blue light and 260° C. phosphor temperature is only 6% for an Inventive Example III while a Comparative Example II (no calcium) shows a decrease of 31%, as can be seen from Table II:

TABLE II

Sample composition	Inventive/Comparative	relative emission intensity after 1 h, 10 W/cm <sup>2</sup> blue flux, $T_{\text{phosphor}} = 260^\circ\text{C}$ .
$(\text{Ba}_{0.48}\text{Sr}_{0.48}\text{Ca}_{0.02}\text{Eu}_{0.02})_2\text{Si}_{4.9}\text{O}_{0.04}\text{N}_{7.96}$	Inventive Example III	94%
$(\text{Ba}_{0.49}\text{Sr}_{0.49}\text{Eu}_{0.02})_2\text{Si}_{4.9}\text{Al}_{0.1}\text{O}_{0.1}\text{N}_{7.9}$	Comparative II	69%

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Further more the optical properties of pcLEDs comprising the material according to Inventive Example III and Comparative Example II were investigated. FIG. 4 shows the total emitted power of the pcLEDs (red phosphor layers on a blue LED, 444 nm peak emission) vs. the layer thickness both for the material of Inventive Example III (diamonds) and Comparative Example II (triangles). For both series, the power decreases with layer thickness, however, the pcLEDs with the material according to the invention always have a higher output power.

FIG. 5 shows two emission spectra of red phosphor layers on a blue LED (444 nm peak emission) of layers out of the material according to Inventive Example III ("A", solid line) as well as the comparative Example II ("B", dashed line) having identical blue transmission. The pcLED using the material according to the invention delivers approx. 6% percent additional light.

FIG. 6 shows a plot of the total emitted power as a function of the CIE x color coordinate for the two pcLEDs of FIG. 5 ("A" and "B" have the same meaning as in FIG. 5). The CIE-color coordinate serves as a measure of the ratio of red to blue light in the LED emission spectrum. From the figure it can clearly be seen that the efficiency advantage of the inventive material increases with increasing conversion of light.

The particular combinations of elements and features in the above detailed embodiments are exemplary only; the interchanging and substitution of these teachings with other teachings in this and the patents/applications incorporated by reference are also expressly contemplated. As those skilled in the art will recognize, variations, modifications, and other implementations of what is described herein can occur to those of ordinary skill in the art without departing from the spirit and the scope of the invention as claimed. Accordingly, the foregoing description is by way of example only and is not intended as limiting. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these

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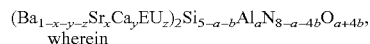
measured cannot be used to advantage. The invention's scope is defined in the following claims and the equivalents thereto. Furthermore, reference signs used in the description and claims do not limit the scope of the invention as claimed.

## 5 Methods

The average diameter can be measured by the following procedure based on light scattering (see XU, R. Particle Characterization: Light Scattering Methods, Kluwer Academic Publishers, Dordrecht (2000)). The powder to be measured is suspended in a liquid media such as demineralized water with a dispersant added to stabilize the suspension. The particle suspension is then analyzed by laser diffraction to obtain information about particle size distribution through measurements of scattering intensity as a function of the scattering angle and the wavelength and polarization of light based on applicable scattering models. Such a method is absolute in nature without the need to calibrate instrument. Alternatively, particle sizes can be directly measured with a microscope (optical microscope, scanning electron microscope) and particle size distributions can be calculated based on image processing procedures.

The invention claimed is:

1. A light emitting diode structure comprising a material according to the formula:



$$\begin{aligned} 0.3 \leq x \leq 0.9, \\ 0.01 \leq y \leq 0.1, \\ 0.005 \leq z \leq 0.04, \\ 0 \leq a \leq 0.2 \text{ and} \\ 0 < b \leq 0.2. \end{aligned}$$

2. The light emitting diode structure according to claim 1, having an average particle size distribution of  $\geq 6 \mu m$ .

3. The light emitting diode structure according to claim 1, wherein  $0.02 \leq y \leq 0.04$ .

4. The light emitting diode structure according to claim 1, wherein  $0.35 \leq x \leq 0.8$ .

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